Constraints on Self Interacting Dark Matter from Small Scale Structure

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The core-cusp problem remains as one of the unresolved challenges between observation and simulations in the standard ΛCDM model for the formation of galaxies. Basically, the problem is that ΛCDM simulations predict that the center of galactic dark matter halos contain a steep power-law mass density profile. However, observations of dwarf galaxies in the Local Group reveal a density profile consistent with a nearly flat distribution of dark matter near the center. A number of solutions to this dilemma have been proposed. We investigate the possibility that the dark matter particles themselves self interact and scatter. The scattering of dark matter particles then can smooth out their profile in high-density regions. We also summarize a theoretical model as to how self- interacting dark matter may arise. We implement this form in simulations of self-interacting dark matter in models for galaxy formation and evolution. Constraints on this form of self-interacting dark matter will be summarized.

Keywords: cosmology: interacting dark matter — cosmology: theory

1. Introduction

Until a few years ago, the most satisfactory cosmological scenario was that comprised of ordinary matter, cold dark matter and a cosmological constant. This model satisfies observational cosmology, for a spectrum of density fluctuations that is nearly scale-invariant and adiabatic. However, in recent years it has been pointed out that conventional models of collision-less cold dark matter lead to problems with regard to galactic structure. They are only able to fit the observations on large scales ($\gg 1Mpc$). Also, N-body simulations in these models result in a central singularity of the galactic halos[1] and a large number of sub-halos[2] than observed. A number of other inconsistencies have been discussed.[3,4].

It has been shown[5] that a possible way to avoid these problems is to hypothesize *self-interacting dark matter*. Allthough self-interacting models lead to spherical halo centers in clusters, which is not in agreement with the ellipsoidal centers indicated by strong gravitational lens observations[6] and by Chandra observations[7]. However, self-interacting dark matter models are well motivated as an alternative model.

It is a well-accepted fact that plausible candidates for dark matter are elementary particles. The key property of these particles is that, they must have a weak scattering cross-section and be non-relativistic. The Spergel-Steinhard model has motivated many follow-up studies[8–10]. However, several authors have proposed models in which a specific scalar singlet that satisfies the self-interacting dark matter properties is introduced in the standard model.

There are several small scale cosmology problems that we still do not have solutions for: (i) The core cusp problem in the difference between observation of the dark matter density profiles of the dwaft galaxy and N body simulations. In theoretical simulations[11] the dark matter profile density increases steeply with decreasing galactic radius. However, observations of dwarf galaxies indicate that the density profiles are flat. (ii) The dwarf galaxy problem in simulations of the ΛCDM predicts a number of the dwarf galaxies is higher in observation. (iii) The too-big-to-fail problem, the ΛCDM simulations predict to dense to have bright satellites. In this talk we study on the Self Interaction Dark Matter model and its effect on the small scale structure of galaxies. We show that the mass of the Self Interaction Dark Matter in this model in about an MeV based to comparison with tobservations.

The range of mass for SIDM is from MeV with a mean free path and total cross section over mass from 0.1 cm^2/g until 100 cm^2/g will be close to the observation in the inner DM halo and it can be solve the core-cusp and the missing satellite problems of the ΛCDM model. In our model the cross section over mass σ/m is in the range of 4 to 5 cm^2/g. In the large scale structure there is no difference with normal CDM but in small scale structure the core is consistent with all of the observational constraints. In general, SIDM would make no difference from ΛCDM on large scales, however, individual galaxies would have dense spherical cores and a higher velocity dispersion. However, on the small scale, we still do not yet have any observational constraint. With the hydrodynamic simulation, we can see the effectively the small scale structure of the dark matter. We have used the Planck temperature and WMAP polarization data to constrain the self interacting dark matter. In this talk we briefly review the model, the he CMB constraints a the results of simulations.

2. Structure formation in a SIDM Universe

In previous work[12] it was deduced that this dark matter particle only weakly interact with ordinary matter through the Higgs Boson of the standard model. The mass range for the dark matter is from 4.7 MeV to 29 MeV. Our dark matter is non-relativistic with a decoupling temperature ∼ 1eV. Dark Matter does not interact with any particles in the standard model except for the Higgs Boson, so we do not need to deal with collision terms. in the Boltzmann equation. The Self-interacting Dark Matter in the 331 models[12] has mass range of 5.5 MeV $\leqslant m_h \leqslant$ 29 MeV. This means that our dark matter particle is non-relativistic driving the decoupling era with a decoupling temperature about 1eV.

The Boltzmann equation reduces to the form

$$\frac{dn_h}{dt} + 3Hn_h =< \gamma >_H \tag{1}$$

The thermal average of the decay rate is given by

$$\Gamma = \frac{\alpha(\Theta T)^2}{8\pi^3 n_H} e^{m_1/T} \tag{2}$$

where α is an integration parameter that can be taken to be 1.87. We define

$\beta = n_h/T^3$ and in the radiation dominated era we can write

$$\frac{d\beta}{dT} = -\frac{\Gamma\beta}{KT^3} = -\frac{\alpha}{8\pi^3 K e^{m_1/T}}(\frac{\Theta}{T^2})^2 \tag{3}$$

where $K^2 = 4\pi^3 g(T) 45 m_{Pl}^2$, with the Planck mass $m_{Pl} = 1.2 \times 10^{19}$ GeV, and the degeneracy, $g(T) = g_B + (7/8)g_F = 136.25$, where g_B and g_F are the relativistic bosonic and fermionic degrees of freedom, respectively. Here we take $T = m_1$ since this regime gives the largest contribution to β.

Hence,

$$\beta = \frac{\alpha\Theta^2}{4\pi^3 K m_1^3} \tag{4}$$

Now, the cosmic density of the h_0 scalar is

$$\Omega_h = 2g(T_\Gamma)T_\gamma^3 \frac{m_h \beta}{\rho_c g(T)} \tag{5}$$

where $T_\gamma = 2.4 \times 10^{-4}$ eV is the present photon temperature, $g(T_\gamma) = 2$ is the photon degree of freedom and $\rho_c = 7.5 \times 10^{-47} h^2$, with h = 0.71, being the critical density of the universe. We take $m_h = 7.75$ MeV, v = 174 GeV, $a_5 = 0.65$, -a_6 = 0.38 and $m_1 = 150$ GeV. Thus, we obtain $\Omega_h = 0.3$ andwithout imposing any new fields or symmetries, the 3-3-1 model possesses a scalar field that can satisfy all the properties required for the self-interacting dark matter and does not overpopulate the Universe.

3. Constraint with CMB and Galaxy simulation

We now consider the relation between the dark matter density and galactic radius. The model for self interacting dark matter should have a core size less than 2kpc on the scale of dwarf galaxies. For the scalar h the candidate we have cosmological parameter

$$\Omega_h = \frac{\rho_h}{\rho_0} = 2g(T_\gamma)T_\gamma^3 \frac{m_h . \beta}{\rho_c g(T)} \tag{6}$$

and

$$\Omega_{SIDM} = \frac{\rho_{SIDM}}{\rho_0} = 2g(2.4 \times 10^{-4})^3 \mathrm{eV} \frac{4.7 \text{ MeV}\beta}{7.5} \tag{7}$$

For our simulations, we set the initial conditions for the ENZO code using cosmological parameters: h = 0.7, $\rho_m = 0.266$, $\rho_\Lambda = 0.734$, $n_s = 0.963$, and $\sigma_8 = 0.801$.

The Friedmann equation for a the model including SIDM is

$$H^2 = \frac{8\pi G}{3}(\rho_\Lambda + \rho_{SM} + \rho_{DM} + \frac{1}{2}) \tag{8}$$

We study the simulation of the galaxy formation in $10^{10} M_\odot$ halos of Dark matter with galaxy formation with non zero cross section. We study the galaxy formation with stellar masses in self interacting dark matter (SIDM) with cross section over mass in the range from 3.7 to 5.2 cm^2g^{-1}. The Lambda Cold Dark Matter model treats the DM as non relativistic and collision-less. However, dark matter has a weakly interaction with the Higg Boson in the Satndard Model of the particles physics. That model also agrees with the observational data on the large scale structure.

In our simulation we use a cosmological model with parameters $\Omega_\Lambda = 0.734, \Omega_m = 0.266, \Omega_b = 0.0449, n_s = 0.963, h = 0.71, \sigma_8 = 0.801$. We start with isolated halo galaxies with a stellar mass of $M_{star} = 1.4 \times 10^{11} M_\odot$ and temperature $T = 10^4$K with in a box size of 50 Mpc h^{-1} For the Cold Dark Matter run we use a standard[11] initial radial density profile. We find that galactic structure is best fit with an SIDM mass of $\sim$ MeV.

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